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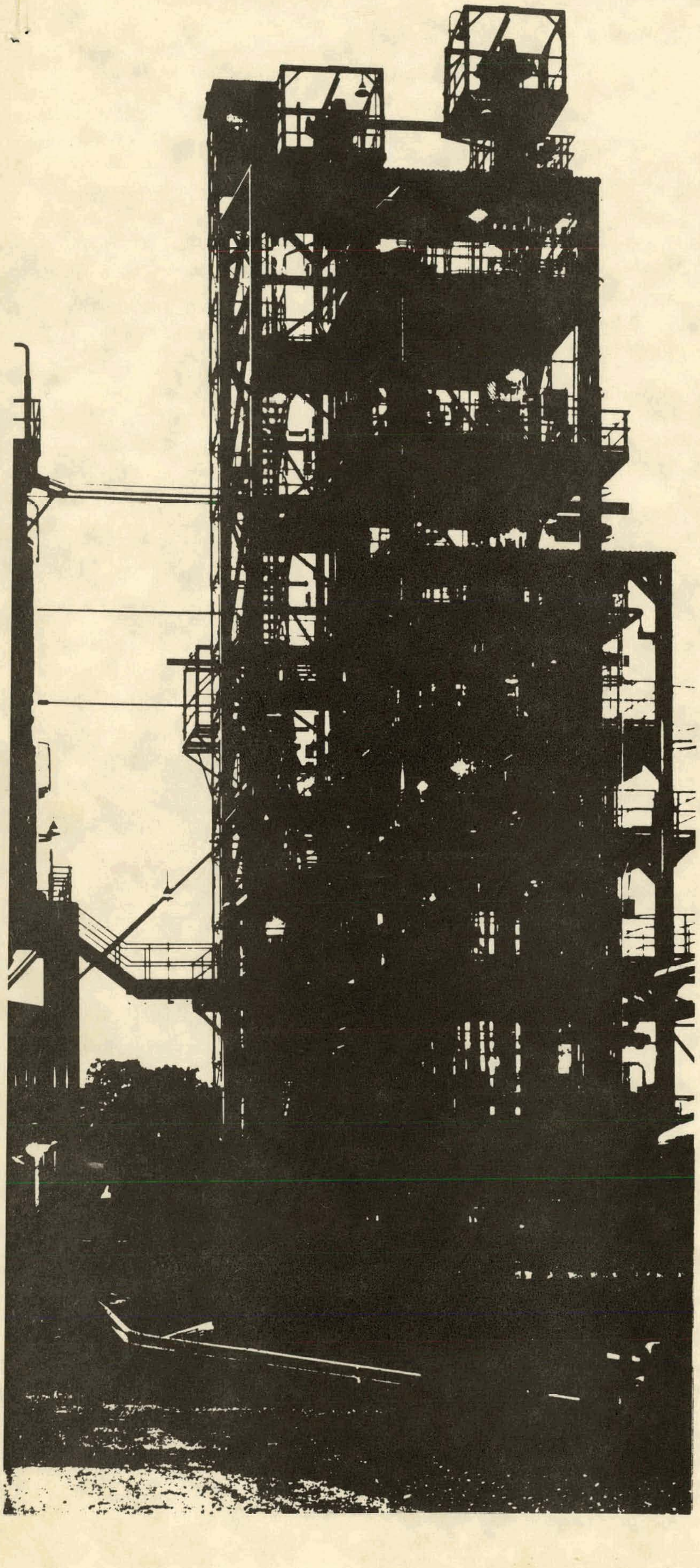

Westinghouse Fluidized Bed Coal Gasification System: Experience & Plans

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DISCLAIMER

WESTINGHOUSE FLUIDIZED BED COAL GASIFICATION SYSTEM
EXPERIENCE AND PLANS

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ABSTRACT

A comprehensive program is underway to evaluate the Westinghouse fluidized bed coal gasification system for a combined cycle power plant. Such a plant is expected to be lower in capital costs, lower in pollutant emissions and have the potential for higher overall plant efficiency when compared with conventional power plants. A 15 ton/day Process Development Unit (PDU) has been constructed at Waltz Mill, PA, to investigate the coal gasification process, and testing has been in progress since early 1975.

Most of the reactor design criteria initially specified for the PDU have been realized in the test operations completed to date. Test runs have been conducted with a variety of coal and char feedstocks including non-caking or mildly-caking Wyoming and Indiana coals as well as highly caking Pittsburgh coals. Steady state tests of extended times have been achieved with high carbon utilization efficiencies and production of acceptable product fuel gas. Plans are in progress to demonstrate the process on a larger scale.

INTRODUCTION

Since late 1972, Westinghouse Electric Corporation, under contract with the U. S. Department of Energy, has been developing an advanced fluidized bed gasification process capable of supplying a clean, low-Btu fuel gas for electric power generation utilizing gas turbines or combined cycle generating systems. The goal of the program is to develop a system which meets a highly diverse set of specifications: it must be capable of accepting a wide variety of run-of-mine coals of variable size and composition; it must provide a fuel gas which has properties within the tolerance band of a modern gas turbine; it must meet all environmental standards; and it must be efficient, reliable and economical when compared with alternate methods of coal conversion.

Work on the program has proceeded along four lines: bench scale laboratory experiments and analytical studies, process development unit (PDU) tests, full scale combustion evaluations and scale-up studies. The major effort since inception of the program has been directed toward operation of the 15 ton/day PDU located at Waltz Mill, Pennsylvania. This unit was built in 1973 and 1974, and it has been in operation since January 1975. The ultimate objective is a full scale commercial demonstration plant generating electric power from coal.

GASIFICATION/POWER GENERATION

Coal gasification for power production produces a clean fuel gas, with minimal sulfur and ash, which can be utilized either at atmospheric pressure in a conventional gas-fired boiler or at elevated pressure in a gas turbine combustor. Perhaps the largest potential use of coal gasification is integration with combined cycle generating systems. The coal gasification combined cycle (CGCC) system was recently recommended by a National Research Council panel as the most promising application of low-Btu gas for improving conversion efficiencies and economics of power generation. The potential advantages of CGCC generating systems over other coal based generating systems include:

- higher overall efficiencies - coal to bus bar,
- lower capital investment costs,
- markedly reduced environmental emissions.

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- lower cooling water requirements, and
- intermediate power duty cycles.

Gasification may also be useful in the future preparation of a clean fuel for an MHD or a fuel cell power plant.

Desirable gasifier characteristics for power systems are basically simplicity, flexibility and reliability.

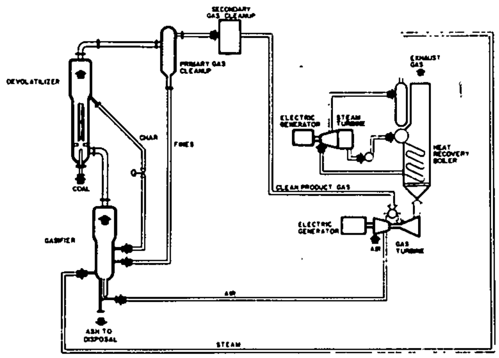
- Simplicity - easy to operate and easy to maintain
- Flexibility- process a wide variety of coal feedstocks and sizes, operate with high turndown ratios, capability for quick shutdowns/restarts, and no gross instabilities
- Reliability- availability equal to or greater than conventional utility power generation systems

The Westinghouse gasification process is based on advanced fluidized bed technology and is tailored to gas turbine combined cycle power generation system requirements. The fluidized bed coal gasification system can be coupled with a combined cycle power plant as shown in Figure 1. A two-stage fluidized bed process gasifies coal using air and steam at 1600-2100°F temperatures and 15-20 atmospheres pressure. Sulfur may be removed from the high temperature, 1400-1700°F, gases using a limestone or a dolomite sorbent. The calcium sulfide is processed for disposal, regenerated for reuse in combination with sulfur recovery or oxidized for sulfur retention and disposal as the sulfate. Particulates are removed from the hot gases by a multistage system which may include conventional cyclones, high efficiency cyclones or granular bed filters.

The fuel gases, 90-160 Btu/scf, flow to the gas turbine combustor where they burn with excess air to provide hot gases for expansion through the gas turbine. Sensible heat, in the gases leaving the gas turbine, is recovered in a heat recovery boiler that provides steam for the steam turbine. About half the electrical energy is produced by the gas turbine generator and half by the steam turbine generator. The gas turbine also drives the main compressor for air flowing to the combustor and gasification process.

The Westinghouse fluidized bed process has the potential to overcome limitations of other gasification systems while providing an economic gasification system for combined cycle power plants. Although this advanced gasifier concept is unique, it is composed of subsystems that have been successfully demonstrated in other processing systems.

FIGURE 1 WESTINGHOUSE COAL GASIFICATION POWER GENERATION SYSTEM



COAL GASIFICATION PROCESS AND PDU

The main reactor subsystems of the Westinghouse fluidized bed process are the devolatilizer and the gasifier. Crushed coal is fed to the bottom of the devolatilizer reactor, a fluidized bed operating at 1600-1800°F. In this unit, devolatilization and partial hydrogasification are combined in a recirculating fluidized bed to produce a product gas rich in CO, H_2 and N_2 with smaller amounts of methane and other hydrocarbons. The dry coal is introduced into the devolatilizer through a central draft tube in which coal, hot gases and recirculating char flow upward at a velocity of 25-30 fps. The hot solids recirculate downward in the annulus around the draft tube at weight rates of 40-100 times the coal feed rate to prevent agglomeration of the fresh coal as it passes through its sticky phase.

Sulfur in the coal can be removed through the addition of crushed dolomite near the top of the devolatilizer bed. Dolomite reacts with hydrogen sulfide in the fuel gases to form calcium sulfide. Sulfided dolomite and char separate in the bed because of density and particle size differences. Each is withdrawn from the reactor through separate drawoff ports The devolatilizer is expected to operate at a mildly endothermic condition, and the heat for the reactions taking place there is supplied by off gases from the gasifier.

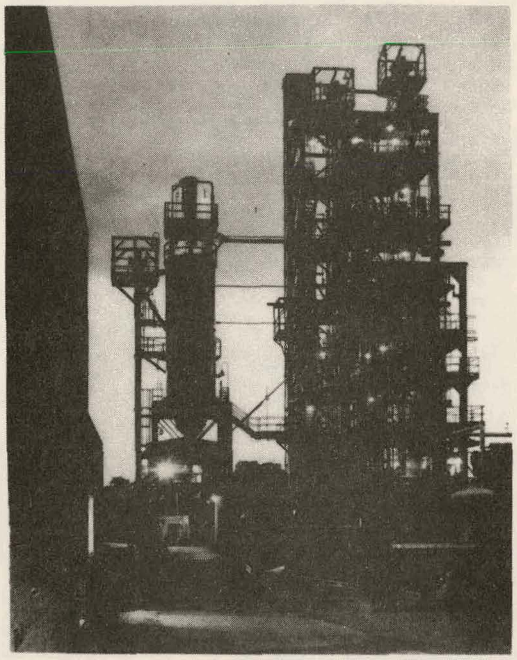
Gasification of the char produced in the devolatilizer is carried out in the gasifier. In the lower portion of the gasifier, char fines produced in the devolatilizer are combusted with air to provide the basic heat source for the process. Product gases of CO_2 and steam are produced. In the upper portion of the gasifier, steam reacts with coarse char to form the CO and H_2 rich stream.

which goes to the devolatilizer. The combustor also causes ash to reach its plastic stage, agglomerate and fall out of the fluidized bed of char. It is removed at the bottom of the reactor as a coarse waste stream. In the PDU, the devolatilizer and gasifier reactors are designed for series and independent operation for flexibility in experimental design. Thus, the devolatilizer can be studied separately from the gasifier and the two subsequently integrated when each is better understood. The PDU design parameters are summarized in Table 1 and the completed plant is shown in Figure 2.

TABLE 1 PDU DESIGN CONDITIONS

Capacity	15 Tons/Day
Pressure	300 PSI
Temperature	2600 °F

FIGURE 2 WESTINGHOUSE FLUIDIZED BED COAL GASIFICATION PDU



PDU RESULTS

The developmental program to evaluate the feasibility of the two reactor concepts was designed to proceed from the simple to the complex. Hence, each reactor system was to be operated independently prior to combined operation in an integrated system. These tests were categorized as shakedown, reactor evaluation and feedstock characterization tests.

Following system shakedown in early 1975, the devolatilizer reactor was evaluated using a variety of coal feedstocks at various process conditions. These tests were successful in demonstrating feasibility of this portion of the process. The coals used included a lignite char, a Western sub-bituminous coal, an Indiana #7 bituminous coal and two Eastern bituminous coals from the Pittsburgh and Upper Freeport seams. The latter two coals were highly caking varieties as measured by Gieseler plasticity and free-swelling properties. Both coals had plasticity indices of greater than 25,000 and swelling indices of 8 or greater. All of the coals were successfully devolatilized in the fluidized bed reactor at temperatures from 1400-1600°F at 225 psig. Nominal coal feed rates of 300-1000 lb/hr were achieved, and char product amounted to about 65% of the feed. Investigations were conducted to produce reactor design data for scaleup to larger sizes and these included: effects of feed rates, coal particle size, freeboard velocity, temperatures, gas composition, bed height on product char and gas characteristics, and fluidization behavior in the bed.

Following devolatilizer evaluations, the gasifier reactor evaluations began in late 1976. A series of shakedown tests were conducted to determine fluidization characteristics of char and ash beds. A series of 16 highly successful test runs at temperature and pressure and with continuous solids feed and withdrawal were then conducted using a variety of feedstock materials. These materials included coke breeze from Pittsburgh seam coals; char from the PDU devolatilizer from Indiana #7, Pittsburgh, and Upper Freeport seam coals; and char from the FMC COED process from both Utah and Western Kentucky coals. In addition, a number of coals were processed directly in the unit without pretreatment by devolatilization or oxidation. These included Wyoming sub-bituminous coal, Indiana #7 coal and Pittsburgh seam coal. During these tests, the reactor was operated at 1750-2100°F and 225 psig, at feed rates from 500-1100 lb/hr. Ash agglomerates were produced from each char feedstock and were continuously withdrawn at levels of 45-97% ash. Separation of ash and char in the bed was distinct and controllable. Startup by autogenous char combustion with air; continuous combustion, gasification and agglomeration; and reliable safe shutdown were achieved for all feedstocks. Tables 2 and 3 as well as Figure 3 illustrate several important results with these tests. These PDU tests demonstrated that the gasification concepts are feasible and can be operated efficiently and reliably. Table 4 is a summary of significant accomplishments.

TABLE 2 DEVOLATILIZER TEST COALS

Parameters	Wyoming Sub-C Sorensen	Indiana #7 Minnehaha	Pittsburgh #8 Montour	Pittsburgh Upper Freeport Renton
Volatiles	36	32	35	35
Carbon	41	43	49	54
Moisture	20	16	6	2
Ash	3	9	10	9
Free Swelling Index	0	2	7-9	8-9
Gieseler Plasticity - ddm	0	250	25,000	30,000

TABLE 3 GASIFIER TEST MATERIALS

Materials	Relative Reactivity	Particle Size, μm	
		Coarse	Fines
Pittsburgh Coke Breeze	1.0	800	200
PDU Pittsburgh Char	2.5	1300	250
PDU Indiana Char	10.0	1100	200
FMC Kentucky Char	12.0	200	200
Wyoming Sub-C Coal	-	1100	-
Indiana #7 Coal	-	1000	-
Pittsburgh Seam Coal	-	800	-

FIGURE 3 MATERIAL FEEDSTOCKS AND PRODUCTS FROM THE PDU

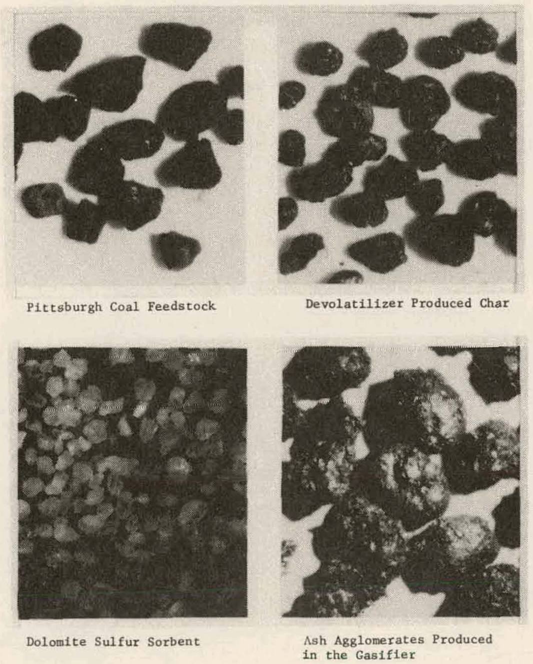


TABLE 4 WESTINGHOUSE COAL GASIFICATION ACCOMPLISHMENTS

Coal Gasification PDU
- Designed, Built and Successfully Operated for 3 Years
  - Hardware Designs Improved and Problems Solved
  - Reliable and Safe Operating Techniques Developed

Gasification Process
- Demonstrated with a Wide Variety of Feedstocks
  - Devolatilizer with Caking Coals
  - Gasifier with Various Chars
  - Gasifier with Direct Coal Feed

Scaleup Conceptual Designs of Gasification Process
- Completed for Application
  - 50 T/Hr Gasifier, Commercial Appl.
  - 3-5 T/Hr Gasifier, Rapid City Retrofit

Low-Btu Gas Combustion
- Demonstrated in Full Scale Turbine Combustor with Simulated Low-Btu Gas

Technical Support Program
- Conducted in Support of PDU and Scaleup Design
  - Bench Scale Tests of Devolatilizer and Gasifier
  - Turbine Effects Experiments
  - Hot Gas Cleanup Experiments
  - Analytical Process Models

SCALEUP AND SUPPORT STUDIES

Preliminary studies have been conducted to compare the cost of the Westinghouse gasification process with alternative processes. Also, a conceptual design for a 50 ton/hour gasification system was completed, and an appropriation cost estimate prepared. The basis for the system design was to determine gasification capacity to operate with a large utility-type gas turbine generator. Basic design theories, equipment configurations, process flow sheets, principal dimensions and operating principles were included in this study effort. The study was completed and reported in mid 1975. In addition, full scale combustor tests have been conducted with a simulated low-Btu fuel gas using the standard W501D turbine combustor housing and a modified combustor basket. The tests have shown that a low-Btu gas can be efficiently combusted in state-of-the-art turbine hardware with low emissions.

More recently, conceptual designs and cost estimates have been developed for conversion of the existing DOE pilot plant at Rapid City, SD, to a low-Btu Westinghouse process facility. A coal gasification rate of 2-3 ton/hour is judged to be the maximum attainable with existing coal preparation, gas quench and gas cleaning systems.

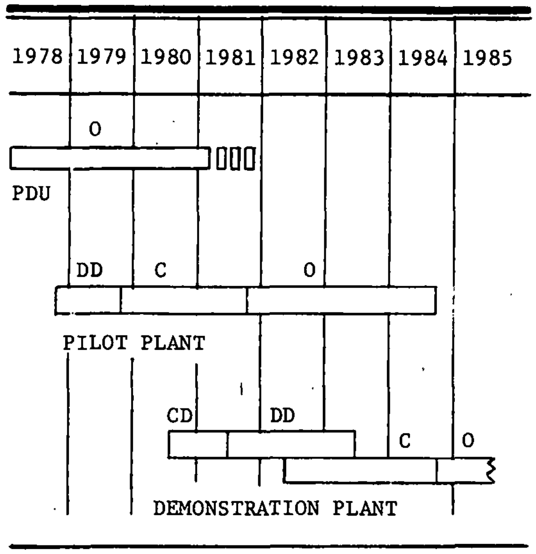
In addition to PDU operation and scaleup studies, a basic part of the Westinghouse Coal Gasification Program includes support studies which are conducted on process technology to provide PDU design data, to project operating conditions for the PDU, to provide troubleshooting capability during PDU operation and to develop commercial plant design data. Primary areas of investigation are: fluidization and fluid particle systems, coal behavior, ash agglomeration, sorbent behavior, reactor analysis, hot gas cleaning and turbine effects.

FUTURE PROGRAM

During the remainder of the PDU program, the two reactors will be integrated and run as a complete system with the gasifier supplying heat and fluidizing gas for the devolatilizer and the devolatilizer providing char for the gasifier. Various control strategies will be tested to simulate combined cycle load-follow applications typical of utility requirements. Special emphasis will be placed on product characterization and on such downstream equipment such as gas cleaning components, heat recovery equipment and turbine components. In addition, some tests will be conducted with the gasifier blown with oxygen rather than with air.

A scaleup plan has been developed which leads to demonstration of a commercial size plant in the early 1980s. Significant features include the development of a large cold flow model to evaluate gasification reactor geometry configurations, design characteristics and operating parameters. This information, continued with scaleup gasification performance data from the proposed Rapid City pilot plant program, would provide the basis of designing a commercial size demonstration plant combining the gasification and power generating systems. A suggested schedule for these efforts is shown in Figure 4.

FIGURE 4 PROPOSED COAL GASIFICATION-POWER GENERATION DEMONSTRATION PROGRAM SCHEDULE



Legend: C-Construct
CD-Conceptual Design
DD-Detail Design
O-Operate

ACKNOWLEDGEMENTS

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